A wind tunnel study of flow distortion at an ultrasonic anemometer sensor on a microwave tower in Himeji, Japan

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Abstract

We observed atmospheric turbulence using a microwave tower in the city of Himeji. A tower distorts the airflow. Therefore, an ultrasonic anemometer is usually installed on a horizontal pole located upstream of the tower. However, there is no general theory concerning the distance between sensor and tower, because different towers have varying structures. Therefore, we made a 1/100 scale partial model of a microwave tower in Himeji, where we observed turbulence and performed wind tunnel experiments to examine flow distortion at an ultrasonic anemometer sensor on the tower. The result was a measured wind speed 5% lower than that upstream. Therefore, flow distortion at the sensor caused by the tower is small.

1. Introduction

We observed atmospheric turbulence using a microwave tower in the city of Himeji[1] An ultrasonic anemometer is usually installed on a horizontal pole located upwind of the tower, because the tower distorts the airstream. There is no general theory concerning the distance between sensor and tower, because tower widths, structural member densities and geometries vary greatly (Kaimal and Finnigan, 1993[2]). Therefore, wind tunnel experiments have been conducted by many researchers, such as Hanafusa et al. (1979)[3] and Barlow et al. (2011)[4], to examine the influence of towers. We performed a reduced-scale model experiment of a microwave tower (Fig. 1) to investigate flow distortion at an ultrasonic anemometer sensor installed on the tower. This paper summarizes the results of these wind tunnel experiments.

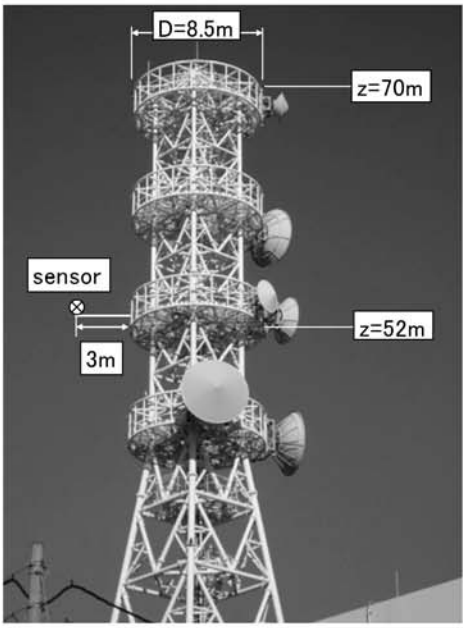

Fig. 1 Photo of microwave tower in Himeji. Left side of picture is toward the south.

2. Method of wind tunnel experiment

The experiment was conducted using a wind tunnel at Kono's laboratory. Dimensions of the working section of the wind tunnel are 3 × 0.3 × 0.3 m (length × height × width). As shown in Fig. 2, the coordinate system used is Cartesian, with the x axis along the wind tunnel, y axis lateral to the flow, and z axis vertical to the floor. A hot wire anemometer (KANOMAX IHW-100) was used to measure wind.

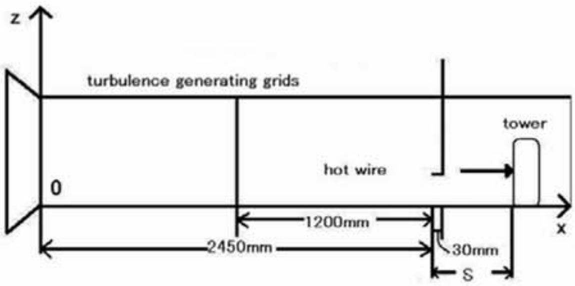

Fig. 2 Working section of wind tunnel and tower model.

The x-type hot wire (Kanomax 0252-T5) was used to measure the streamwise (u) and vertical (w) wind components. Because the hot wire is very sensitive to temperature, the change of room temperature was controlled within ±1.0°C during the experiments.

The sampling rate of wind speed was 1000 Hz, and each sampling period was 10 s. Wind speed was measured at position (x, y, z) = (2450, 150, 113) in mm. A grid turbulence generator developed by Nemoto and Neda (1984)[5] was installed at x=1250 mm. The working section of the wind tunnel is shown in Fig. 2. The Reynolds number was 33,000, with representative length scale 0.1 m and wind speed 5 ms^{-1}.

Figs. 3, 4 and 5 show wind speed, turbulence intensity and momentum flux respectively, which were measured at the position mentioned above. As shown in Fig. 3, the exponent p of the power law in Equation (1) is 0.33, which was calculated using the least squares method for u at z = 30–200 mm.

$$u = u_1 \left(\frac{z}{z_1} \right)^p \qquad (1)$$

Here, u and u_1 are wind speeds at heights z and z_1, respectively. The p=0.33 is close to the value 0.26 obtained from u observed in the urban area of Himeji under neutral conditions[6].

Momentum flux takes the maximum value near the top of roughness blocks (the turbulence generator), if those blocks are placed on the floor of the wind tunnel. However, Fig. 5 shows that the maximum observed momentum flux was at a middle height (z = 90 mm) of the wind tunnel. This is a feature of the grid turbulence generator of Nemoto and Neda. Therefore, in our experiments, u_* is calculated using the momentum flux at z=90 mm in height. The turbulence intensities normalized by u_* are σ_u/u_*=1.70 and σ_w/u_*=1.32 at z=113 mm. It is known that observed turbulence intensities in flat terrain under neutral conditions are σ_u/u_*=2.39 and σ_w/u_*=1.25 (Panofsky and Dutton, 1984)[7]. Values from the wind tunnel experiments are 0.71 and 1.06 times those of turbulence intensities observed in fields, respectively. Therefore, turbulence intensities in the wind tunnel were approximately similar to those from field measurements.

We observed turbulence on a microwave tower in Himeji (Fig. 1). The tower is 70 m in height. The tower composed of steel pipes is built atop a building of 10 m height. The floor of four rings of

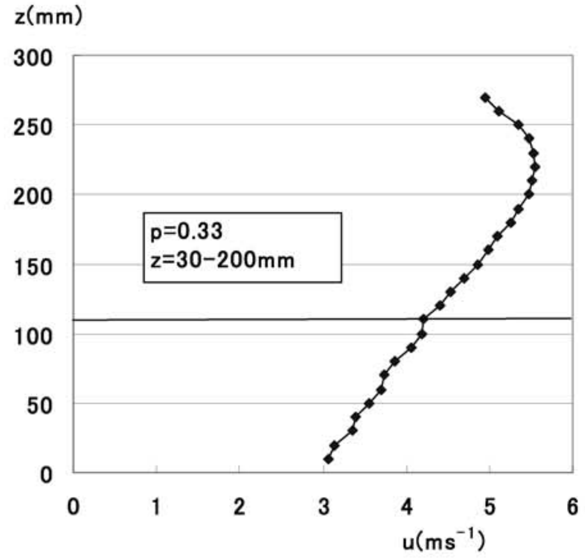

Fig. 3 Vertical profile of u.

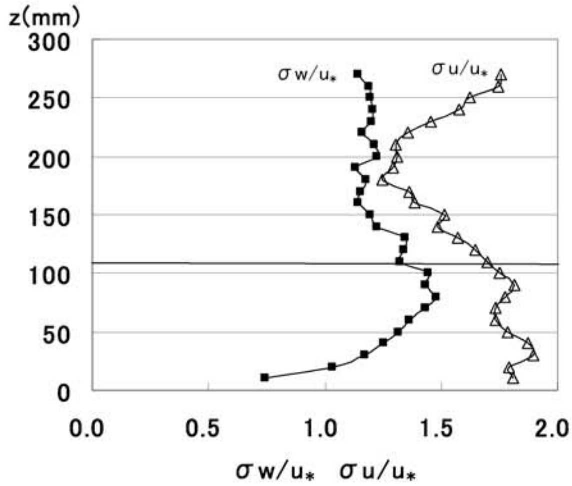

Fig. 4 Vertical profile of σ_u/u_* and σ_w/u_*.

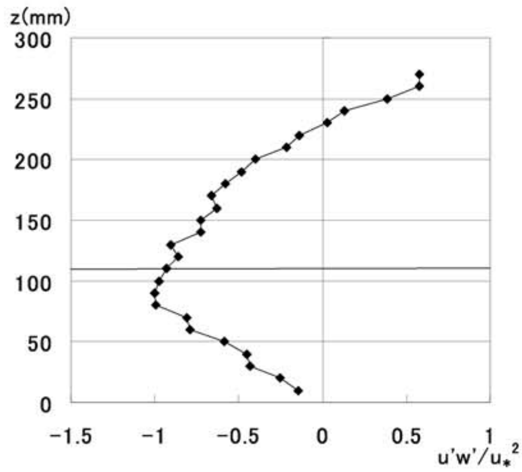

Fig. 5 Vertical profile of momentum flux $\overline{u'w'}/u_*^2$.

the tower in Fig. 1 was made with a steel net (Fig. 7). A partial model of the tower, whose actual height is 40 m to 60 m above ground, was manufactured (Fig. 6). Model scale was 1/100.

The pipes of the model tower were made of stainless steel (SUS304), and floors of the rings were made of wire gauze. The ratio of hole area to total area of the wire gauze was 56%. The diameter of the wire was 0.1 mm, and that of the hole 0.3 mm. In contrast, the hole-area ratio to total area of steel net for the real tower (Fig. 7) was 77%. Therefore, flow resistance of the model net is greater than that of the real net, and this difference is compounded by viscosity. Thus we conducted two experiments, with and without wire gauze.

The structural member density of the model tower is 5.02%, and that of the real tower is 4.59%. The volume ratio without wire net of the model tower to the real one is 0.97, and the surface area ratio is 0.94. The ratio of cross sectional area of the model to that of the wind tunnel is 9.2%.

The hot wire position was fixed at x=2450 mm (Fig. 2), and the model tower position was moved. The traverse distance s in the x direction was from s=0.32D to 3D, where D=85 mm was the diameter of the tower ring. The number of measuring points was 12 or 14. We observed turbulence on the real tower at s = 0.38D = 3 m (Fig. 1).

3. Similarity between wind tunnel and field

The Reynolds number in the wind tunnel was Re=33,000. Thus, the airstream in the wind tunnel was turbulent. The similarity of turbulence between model and real depends on both similarity of turbulence intensity and eddy size. The ratio of model to real for turbulence intensity in x and z components are

$$[\sigma_u / u_*]_m / [\sigma_u / u_*]_r = 0.71 \qquad (2)$$

$$[\sigma_w / u_*]_m / [\sigma_w / u_*]_r = 1.06\,, \qquad (3)$$

where suffixes m and r denote model and real, respectively.

The similarity of eddy size is given by p in Equation (1). The ratio of model to real with p value was p_m/p_r=1.26. Therefore, similarity between model and real was approximately satisfied.

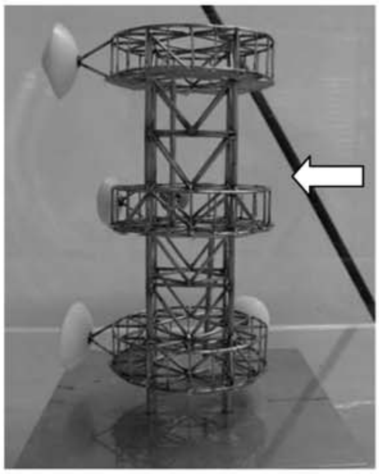

Fig. 6 Photograph of 1/100 scale partial tower model (z = 40 m – 60 m. Arrow shows wind direction in the tunnel.)

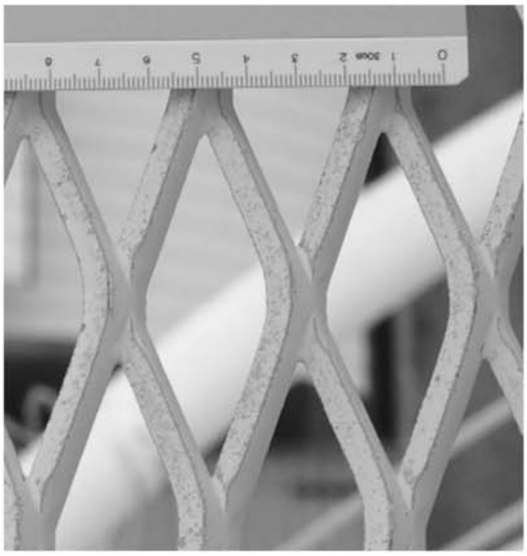

Fig. 7 Steel-net flooring of tower-rings. Minimum division of the scale is 1 mm.

4. Results and discussion

The influence of the tower on measured wind speed u is shown in Fig. 8. The position of s/D= 0.38 in the figure is where we observed atmospheric turbulence at the Himeji tower. Because u was almost constant between s/D = 1 and 3, the average u in that range is regarded as the upstream reference wind speed. The u decreased with decreasing distance s/D, for s/D < 1. The u decreased 4.8% from the upstream reference value in the experiment without wire gauze, and decreased 8% with wire gauze.

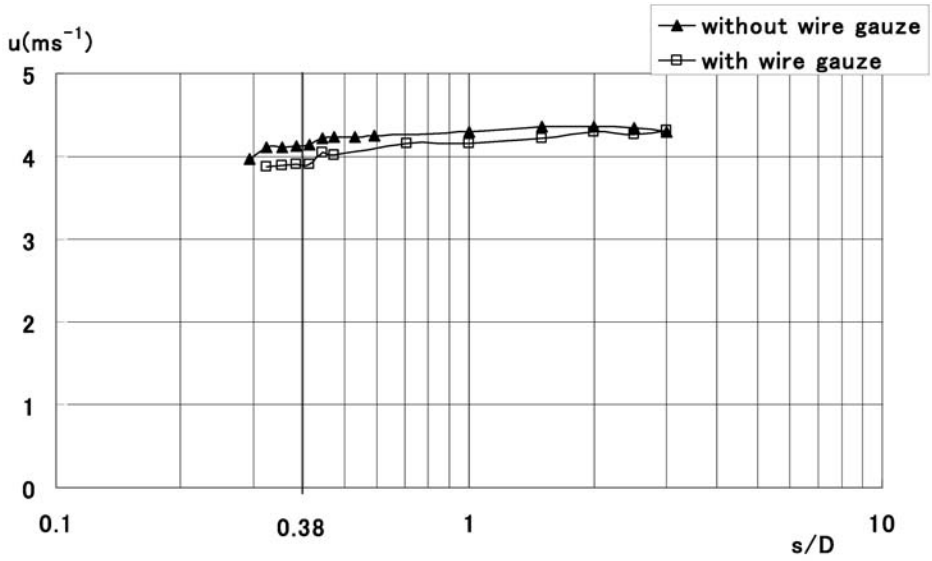

Fig. 8　Measured wind speed u in wind tunnel.

Table 1. Measured u in wind tunnel.

	Without wire gauze			With wire gauze		
	Sensor position	Upstream reference	(S-U)/S	Sensor position	Upstream reference	(S-U)/S
s/D	0.38	1–3		0.38	1–3	
u (ms^{-1})	4.1	4.3	-4%	3.8	4.2	-8%

The measured u is shown in Table 1. We think that 8% was overestimated, because flow resistance of the model wire gauze was too large. We concluded that about 5% of u at the sensor decreased from the influence of the tower.

We also investigated the influence on turbulence velocity σ_u and σ_w, but could not obtain reasonable data. Both σ_u and σ_w varied 5% to 10% between s/D = 1 and 3.0. The provable reason is that pressure fluctuation induced by the tower model reached the range s/D = 1 to 3.0. This was because the ratio of cross-sectional area of the tower model to that of the wind tunnel was 9.2%, which was not small enough. Therefore, turbulence data are omitted here.

A similar wind tunnel experiment was conducted by Hanafusa et al. (1979)[3] for the meteorological tower in the city of Tsukuba. The result was that wind speed decreased more than 15% at s/D=0.38. This is larger than our 5% result for the microwave tower. One of the reasons is the difference of geometry between the two towers. The meteorological tower did not have rings, as did the microwave tower. The other is that the experiment by Hanafusa et al. was carried out in laminar flow, but our experiments were done with turbulence.

5. Conclusions

We observed turbulence using the microwave tower in Himeji. A reduced-scale model experiment was conducted to examine flow distortion at an ultrasonic anemometer installed on the tower. We conclude that wind speed decreased about 5% because of the tower's influence. The flow distortion at the sensor caused by the tower is therefore small.

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